Semantic and repetition priming within the attentional blink: An event-related brain potential (ERP) investigation study

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Abstract

An attentional blink (AB) paradigm was used to directly compare semantic and repetition priming for reported words versus missed words. Three target words (T1, T2, T3) were embedded in a rapidly presented stream of non-word distractors for report at the end of each trial. Whereas T1 was not related to either T2 or T3, T2 and T3 could be unrelated words, semantically related words, or identical. Semantic and repetition priming effects were evident in both behavioral and electrophysiological measures on T3, whether T2 was accurately reported or 'blinked'. These results suggest that semantic and repetition priming effects, under rapid serial visual presentation conditions, are modulated by at least partially overlapping neural mechanisms.
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1. Introduction

Understanding the architecture of the human cognitive system has been the focus of much research. One specific research domain that has contributed to this undertaking is that of visual word processing, with priming being a key tool in the study of a wide range of word-related and memory-related processes.

Numerous studies have shown significant enhancement in the speed and/or accuracy of responses to items, be they words or pictures, when they are preceded by semantically related items (e.g., table–chair) or by themselves (e.g., chair–chair) relative to when they are preceded by semantically unrelated items (e.g., ball–chair). Semantic/associative priming effects are thought to be entirely due to semantic relationships or associative links between primes and targets (Neely, 1991), whereas several additional types of information (e.g., orthographic, phonological) are presumed to contribute to repetition priming effects (e.g., Bentin and Feldman, 1990; Rugg, 1987).

Typically, repetition priming effects are substantially greater and longer lasting than semantic priming effects (Bentin and Feldman, 1990; Henson, 2003; Schacter and Buckner, 1998), consistent with the view that repetition and semantic priming do not arise at least entirely from the operation of a common mechanism(s).

Two main classes of theories have been proposed to account for these two types of priming. According to the more popular view, the prime stimulus exerts a proactive effect on the processing of the target stimulus. The prime stimulus presumably brings about a change in the cognitive system the enables a more efficient and accurate encoding of a subsequent target stimulus when it is related to the prime than when it is unrelated. In the case of semantic priming, for example, activation of the prime stimulus "automatically" spreads to related lexical entries thereby facilitating their subsequent recognition (e.g., Collins and Loftus, 1975; Neely, 1977). Alternatively, a prime stimulus exerts a retroactive effect on target processing, by creating a memory trace that is recruited to support subsequent target processing (Logan, 1988; Tenpenny, 1995; Tulving, 1983).

In the majority of investigations of semantic and repetition priming both the prime and the target are presented above threshold as unmasked visual stimuli. However, a substantial

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parallel literature on masked priming (e.g., Forster and Davis, 1984; Marcel, 1983) also has contributed to our knowledge about word recognition processes. In one variant of this type of paradigm, the prime word is presented briefly and then immediately replaced by a pattern mask (e.g., a series of letters or symbols occupying the same spatial location as the prime) or, in some cases, by the target word itself. In this case, participants are most often unable to report having seen the prime word. Nonetheless, the unmasked target words in these cases are typically associated with faster response times (RTs) and fewer errors when they follow an identity or semantically related masked prime.

There is a large consensus around the hypothesis that in the masked priming paradigm, the mask interferes with the consolidation of long-lasting episodic memories and, therefore, offers a good methodological tool for investigating pure proactive effects (see Bodner and Masson, 2003; Masson and Bodner, 2003, for a different view of priming effects). From this perspective, semantic and repetition priming could originate from the same mechanisms. Forster and Davis (1984) argue that repetition priming consists of a lexical-semantic encoding component which survives masking and a long-lasting episodic component which does not. Assuming that the lexical-semantic component contributes equally to semantic and repetition priming effects, in a masking paradigm these two effects should be identical (Carr and Dagenbach, 1990). In contrast, when the prime stimulus can be consciously perceived, these two priming effects should be dissociable, since the contribution of the episodic component would be stronger for repeated than for merely semantically related stimuli.

The effects of masking on word processing have also been examined within the context of rapid serial visual presentation (RSVP) paradigms. The attentional blink (AB) phenomenon (Broadbent and Broadbent, 1987; Raymond et al., 1992), in particular, has been used to investigate the processing fate of masked words. The AB is observed when two targets (e.g., digits, letters, words, or pictures) appear in close temporal proximity to each other within a RSVP stream. Although the first target (T1) is usually correctly reported, participants show a striking inability to report the second target (T2) if it occurs between 200 and 500 ms after T1. Remarkably, under certain circumstances, when T1 and T2 occur in immediate succession (about 80–100 ms from T1 onset to T2 onset) the AB effect is reduced if not eliminated, an effect called 'lag-1 sparing' (Dell'Acqua et al., 2007a; Potter et al., 1998). According to one favored hypothesis T2 is missed ('blinked') due to a lack of attentional resources, which are otherwise occupied by the processing of T1. Nonetheless, it is generally thought that the 'blinked' item undergoes a fairly high-level of visual processing during the AB.

Behavioral results from semantic priming studies in which the prime has been 'blinked' are mixed, with some showing reliable priming but others not. Broadbent and Broadbent (1987), for example, did not find greater recall of a semantically related T2 relative to semantically unrelated T2 following a 'blinked' T1. By contrast, Maki et al. (1997) found that T2 recall was improved by a semantically related T1; moreover

priming was observed even when the prime word preceding T2 appeared as a distractor. This pattern of results indicates that meaning can at least sometimes be extracted from 'blinked' words. Shapiro et al. (1997) likewise observed that an item presented during an AB, although not identified, is processed to a certain extent, using an RSVP task with three target items. Specifically, they found that an unidentified T2, occurring in the AB period of T1, could nonetheless prime T3, if the two were semantically related (versus unrelated). Shapiro et al. suggested that both perceptual and semantic aspects of 'blinked' words are processed, but that the perceptual information is somehow overwritten or erased from working memory (see also Chun and Potter, 1995; Shapiro and Raymond, 1994; Shapiro et al., 1994), thereby accounting for the finding that these words cannot be overtly reported.

Rolke et al. (2001) modified Shapiro et al. (1997) paradigm, and presented three white target words embedded in a stream of black non-target words. The association strength between T2 and T3 ranged from zero to high. When T2 was recognized, the percentage of correct T3 responses increased as the association strength increased; when T2 was 'blinked', there was no facilitation of T3 identification, with an observed effect in the opposite direction. One reason Shapiro et al. (1997) obtained priming, whereas Rolke et al. (2001) did not may be because the latter placed six intervening items between T2 and T3, whereas the former had just two intervening items. That said, neither group employed a design that was optimal for showing priming. Shapiro et al. used only 13 word pairs that were not only presented repeatedly during the experiment but heavily practiced prior to the experimental session. Rolke et al. (2001) similarly used only 24 sets of target words, all of which were repeatedly shown during the recognition phase of each and every trial. The possibility of learning and bias effects obscuring priming thus cannot be excluded in either of these studies.

In attempt to circumvent the inconsistencies across these behavioral studies, several laboratories have combined behavioral and event-related brain potential (ERP) recordings. ERPs provide a continuous measure of neural processing between a stimulus and a response and can therefore be used to help pinpoint the time at which attention and semantic relationships begin to influence neocortical processing. Vogel et al. (1998) (see also Luck et al., 1996), for example, presented a context word (e.g., doctor) followed by an RSVP string of items. Within the RSVP stream, T1 (e.g., 2222) was presented, followed at various lags by T2 (a word), which was either semantically related (e.g., nurse) or unrelated (e.g., table) to the context word for that trial. At the end of each trial, participants were asked to report whether the digit was odd or even, and to indicate whether the target and context words were or were not semantically related. During AB, there was unequivocal neurophysiological evidence that the processing of the stimuli was not interfered with either at a sensory level (i.e., no suppression of P1 and N1 components reflecting early sensory processing), or at a semantic/conceptual level (as reflected in normal modulation of N400 amplitude by semantic/associative relations, Kutas and Hillyard, 1980). By contrast, the P300, or

P3b, component of the ERP typically related to conscious identification (Donchin and Coles, 1988), or updating of, and consolidation into, working memory, was completely suppressed during the AB, although present in the response to targets presented at lags before and after the AB (Dell'Acqua et al., 2003; Vogel et al., 1998). These results thus would seem to indicate that even though AB occurred, the 'blinked' target word was sensed, perceived, and processed to a semantic/conceptual level. Rolke et al. (2001) likewise found that when an AB effect was induced in an RSVP paradigm, missed words did not elicit a P300, suggesting that they were not explicitly recognized, but did exhibit modulation in their N400 components by semantic relations. Such results suggest (1) that the suppression of processing leading to AB occurs at a post-perceptual stage, that is, after word meaning has been accessed but before an overt report is given, and (2) that the perceptual information extracted from the stimulus input is somehow overwritten or erased from working memory (i.e., prior to consolidation).

In sum, whereas ERP results clearly indicate a relatively high level processing of 'blinked' items to a semantic/conceptual level, behavioral measures have yielded mixed results. One major aim of the current work therefore is to investigate this ERP-behavior dissociation more deeply. To this end, we chose to examine not only semantic priming as in Rolke et al. but also repetition priming, during the AB. Contrary to Rolke et al. and Shapiro et al., in which only a small set of words was used repeatedly, we selected a large set of words, and presented each pair only once. To our knowledge, only Martens et al. (2002) have investigated word repetition priming during AB. Using a variant of the paradigm originally proposed by Duncan et al. (1997), Martens et al. displayed pairs of words in rapid sequence, so as to generate conditions suitable for observing an AB effect influencing T2 report. Repetition and semantic priming effects were probed using a recognition test, which, in different experiments, was either offline (after participants were exposed to the entire set of AB trials), or online (at the end of each AB trial). Semantic priming effects were observed in the offline recognition for T2 whether they were reported or 'blinked'. By contrast, however, repetition priming effects were observed only for reported T2 items, but not for those that were 'blinked'. To interpret this dissociation between repetition and semantic priming effects for words that were missed due to the AB effect, Martens et al. (2002) appealed to the idea that conscious report of a visual stimulus is a consequence of the confluence of sweeps of activation reaching higher-level cortical areas with activation that feeds back from these areas to cortical areas responsible for the early visual processing of these stimuli. On this view, the second of a pair of words in such a scheme (see also Di Lollo et al., 2000; Lamme, 2003) might be missed because the reentrant circuitry necessary for second word consolidation might be interfered with by analogous activity necessary for the generation of a conscious/reportable memory trace for the first word. Even momentary interference with the reentrant circuitry during the AB in this way could corrupt the perceptual representation of T2, which however would not prevent the spread of semantic activation originating from T2 to related concepts. Thus, although there would be no repetition priming given the perceptual corruption of T2, the residual semantic activation would nonetheless support semantic priming.

The present study seeks to extend the work of Martens et al. (2002) by including ERP measures of semantic and repetition priming in a context in which priming effects will be monitored online, that is, at the end of each AB trial. Our specific aim is compare and contrast these two types of priming in a RSVP design (i.e., with masking). Very little work – and none using the AB paradigm – has attempted to compare the effects of semantic and repetition priming directly. In suprathreshold priming paradigms, both semantic and repetition priming are reflected in reduced negativity during the region of the N400 (200–550 ms or so, post-item onset), with somewhat larger effects seen for repeated items than for semantically related items. Of interest, here, therefore will be whether masked semantic and repetition priming also yield identical, somewhat similar or fundamentally different ERP effects, and by extension identical or non-identical perceptual and cognitive operations. If repetition and semantic priming engage different cognitive mechanisms, as suggested by Martens et al. (2002), this difference should be reflected in qualitatively different accompanying ERP modulations. A difference in scalp distribution of the repetition effects, for example, would constitute evidence that these variables do not engage entirely the same cognitive mechanisms. Qualitatively similar priming effects, by contrast, would suggest that the two processes engage closely related, if not identical, mechanisms.

2. Experimental

2.1. Method

2.1.1. Participants

Twenty-five University of Padova undergraduate and graduate volunteers, between the ages of 19 and 31 (mean = 20 years) participated in the experiment. Participants were right-handed, native Italian speakers with no history of neurological disorders, who reported having normal or corrected-to-normal visual acuity and normal color vision. Only trials on which both the first and third targets were correctly reported were analyzed. As a consequence, data of 12 participants were excluded from further analyses due to an excessive error rate, leaving less than ten trials per experimental condition. Therefore, the analysis was carried out on 13 participants (7 women, mean age = 24).

2.1.2. Stimuli and procedure

The stimulus presentation is graphically reported in Fig. 1. All stimuli (4–5 letter strings) were displayed in the center of a gray CRT for a duration of 83 ms each at a viewing distance of 60 cm, resulting in a visual angle of 3.2°.

Each trial consisted of a sequence of 22 events, 19 distractors and 3 targets – D D D D T1 D D T2 D D D D D D T3 D D D D D D D – displayed via RSVP with SOA of 83 ms between successive stimuli. There was thus a 249 ms SOA between T1 and T2, an SOA known to yield a pronounced AB effect. T3 appeared at an SOA of 830 ms relative to T1 and an SOA of 581 ms relative to T2. Distractors were consonant strings presented in the middle of the CRT in black. The target stimuli were green words appearing in the fifth (T1), and red words appearing in the eighth (T2), and fifteenth (T3) positions in the sequence, in the middle of the CRT. To maximize masking, within any given trial, all 22 stimuli in a list had the same number of letters (half 4-letter and half 5-letter). Within any given trial, (1) the initial letter of each target word was different and (2) not more than two letters were shared by any pair of words in a given set. The
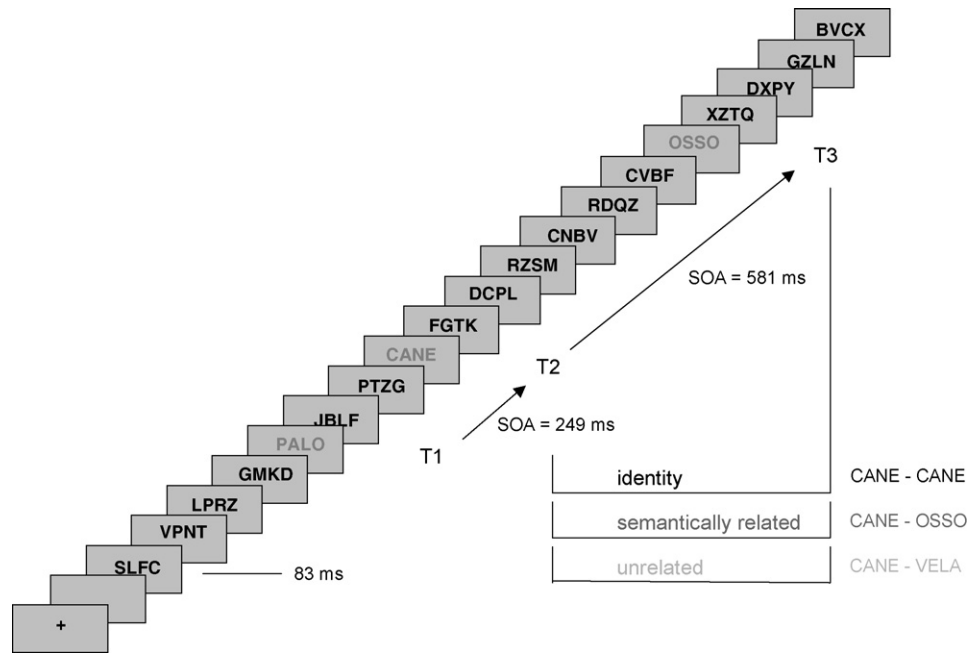
Fig. 1. Schematic depiction of the RSVP presentation used in the present experiment.

360 trials were divided equally into one of three types: (1) 120 identity, where T2 and T3 were the same word (e.g., It. CANE–CANE; Eng. DOG–DOG), (2) 120 semantically related, where T2 and T3 were semantically related (e.g., It. CANE–OSSO; Eng. DOG–BONE), and (3) 120 unrelated, where T2 and T3 were semantically unrelated (e.g., It. CANE–VELA; Eng. DOG–SAIL). Within any given trial, T1 was not semantically related to either T2 or T3, regardless of relatedness condition. Moreover, each T1, T2, and T3 array was unique, such that no array was repeated across trials.

For stimulus construction, 120 T2 words were selected from among four and five character Italian nouns and adjectives in the VELI corpus (1989), each of them was paired with the same, semantically related, and unrelated T3 word, so as to meet the length and orthography constraints stipulated above. On average, T3 is a strong associate of T2. Finally, 120 T1 words were selected to be unrelated to T2 or T3. The stimuli were matched for frequency and orthographic similarity across conditions.

Each trial began with three fixation crosses (+++) in the center of the screen. A spacebar press initiated a 700 ms blank interval followed by the RSVP stream of stimuli. The order of the trials was randomized for each participant separately. At the end of each trial participants typed the three words (T1, T2 and T3) in order of their appearance and without any time pressure. Feedback was given after each trial. Each participant performed 1 block of 15 practice trials, followed by 10 blocks of 36 experimental trials.

2.1.3. EEG recording

Electroencephalographic (EEG) activity was recorded from 19 tin electrodes embedded in an electrode cap, each referenced online to the left mastoid. ERP averages were re-referenced off-line to the average activity recorded over the right and left mastoid sites. Scalp recording sites included: FP1, FP2, Fz, F3, F4, F7, F8, C3, C4, Cz, P3, P4, Pz, O1, O2, T3, T4, P7, P8 (see Pivik et al., 1993). Lateral eye movements and blinks were monitored via electrodes placed at the outer canthus of each eye and an electrode under each eye (referenced to the left mastoid), respectively. Electrical impedances were kept below 5 kΩ. Data were sampled at 250 Hz. The EEG and electrooculogram (EOG) were amplified with a bandpass filter of 0.01–100 Hz.

2.1.4. ERP data analysis

Trials with artifacts due to eye movements, excessive muscle activity or amplifier blocking were eliminated off-line before data averaging. A 200 ms pre-stimulus baseline was used for all analyses. Data with excessive blinks were adaptively corrected as described in Gratton et al. (1983).

Only trials in which participants correctly identified both T1 and T3 were analyzed. Component amplitudes of the ERPs to T1, T2 and T3 were quantified as the mean voltage between 220 and 320 ms (P2) after T1 onset, between 220 and 320 ms (P2) after T2 onset, between 350 and 550 ms (P300) after T2 onset, between 220 and 320 ms (P2) after T3 onset, and between 320 and 550 ms (N400) post-T3 onset. Statistical analyses were carried out by using repeated-measures analyses of variance (ANOVA).

3. Results

3.1. Behavior

Only those trials on which Target 1 was reported correctly (81% of all trials) were included in the analyses. Recognition of
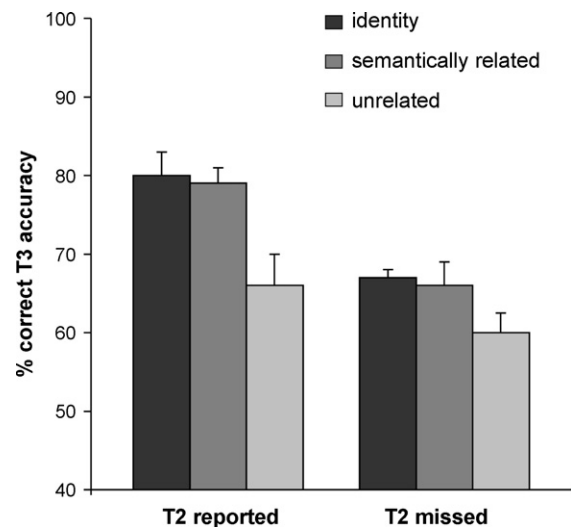

Fig. 2. Percentage of correct T3 accuracy (given T1 reported correctly) as a function of reported vs. missed T2 and the identity (black bar), semantically related (dark gray bar), and unrelated (bright gray bar) conditions.
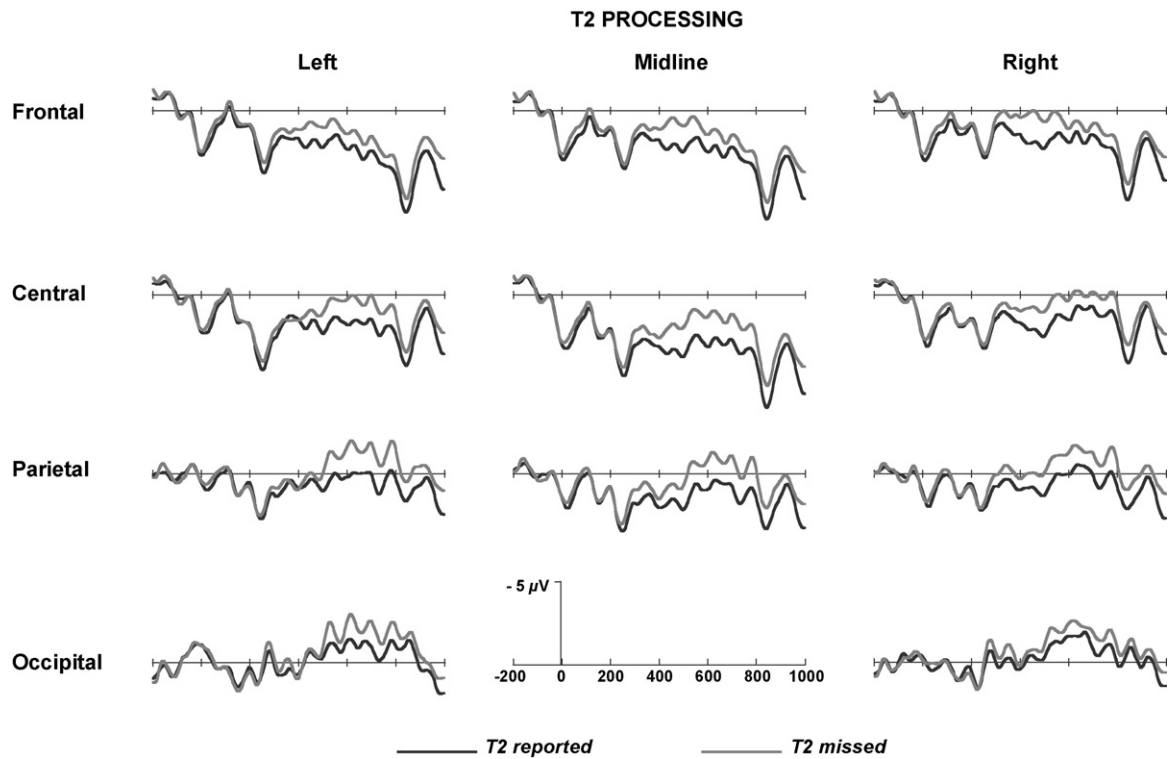
T2 PROCESSING

Fig. 3. Grand average ($N = 13$) ERP waveforms elicited by T2 separately for the two conditions of T2 reported (black line) and T2 missed (gray line). Electrodes shown are a representative subset, including left, midline, and right frontal electrodes (F3, Fz, F4), central (C3, Cz, C4), parietal (P3, Pz, P4), and occipital (O1, O2).

both T2 and T3 were reduced relative to T1, however, T2 recognition was substantially less (40.0%) than T3 recognition (68.0%), $F(1, 12) = 121.58$, $p < .0001$, consistent with the Attentional Blink effect. T3 recognition performance for the three relatedness conditions (identity, semantically related, and unrelated) as a function of whether T2 was or was not reported is depicted in Fig. 2. The percentage of correct detections was significantly higher for T3 words in both of the relatedness conditions relative to the unrelated condition regardless of whether T2 was correctly reported, $F(2, 24) = 13.71, p < .001$, or not reported $F(2, 24) = 3.57, p < .048$. Relatedness specific contrasts revealed a reliable difference between the identity condition and the unrelated condition when T2 was correctly reported, $F(1, 12) = 16.75$, and when T2 was not reported, $F(1, 12) = 4.49, p < .05$, and between the semantic condition and the unrelated condition when T2 was correctly reported, $F(1, 12) = 25.05, p < . 0001$, and when T2 was not reported, $F(1, 12) = 7.02, p < .021$. Moreover, there was no significant difference between the identity and semantic conditions whether T2 was correctly reported $F(1, 12) = 2.19, p > .16$, or not $F(1, 12) = .001, p > .98$.

In other words, significant repetition and semantic priming effects were obtained whether or not T2 was attentionally 'blinked'.

3.2. T2-locked ERPs: 350–550 ms post-T2 (P3)

Mean amplitudes to T2 in the P3 time window were submitted to an ANOVA, with the factors of correctness (reported versus not reported), and electrode (17 levels). As can

be seen in Fig. 3, only T2 items that were correctly reported elicited a reliable P300 component; the ERP to T2 items that were not reported (i.e., 'blinked') were instead characterized by a negative potential in this same time window [main effect of correctness, $F(1, 12) = 7.67, p < .017$]. There were no other main effects or reliable interactions of note.

3.3. T3-locked ERPs: 220–320 ms post-T3 (P2)

The earliest effects of relatedness in the ERP time-locked to T3 were observed in the P2 region.[1] Mean amplitude measures in the P2 time window were submitted to an ANOVA, with factors of T2 correctness (2 levels), relatedness (3 levels) and electrode (17 levels). This analysis revealed a reliable relatedness effect, $F(2, 24) = 3.41, p < .05$, with repeated and semantically related target ERPs producing a bigger positivity than unrelated targets [repeated versus unrelated: $F(1, 12) = 4.42, p < . 05$, and semantically related versus unrelated: $F(1, 12) = 4.69, p < .049$]. No difference was detected between the identity and semantic conditions, $F(1, 12) = .17, p > .68$.

This main effect of relatedness was qualified by an interaction with electrode $F(32, 384) = 4.44, p < .0001$, reflecting an effect most pronounced at frontal electrode

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[1] In addition, an ANOVA was carried out on the ERP time-locked to T1 and T2 in the P2 time range, considering T2 correctness (2 levels), relatedness (3 levels) and electrode (17 levels). As expected, this analysis found no significant results ($Fs < 1$), indicating that the effects were observed only on T3.
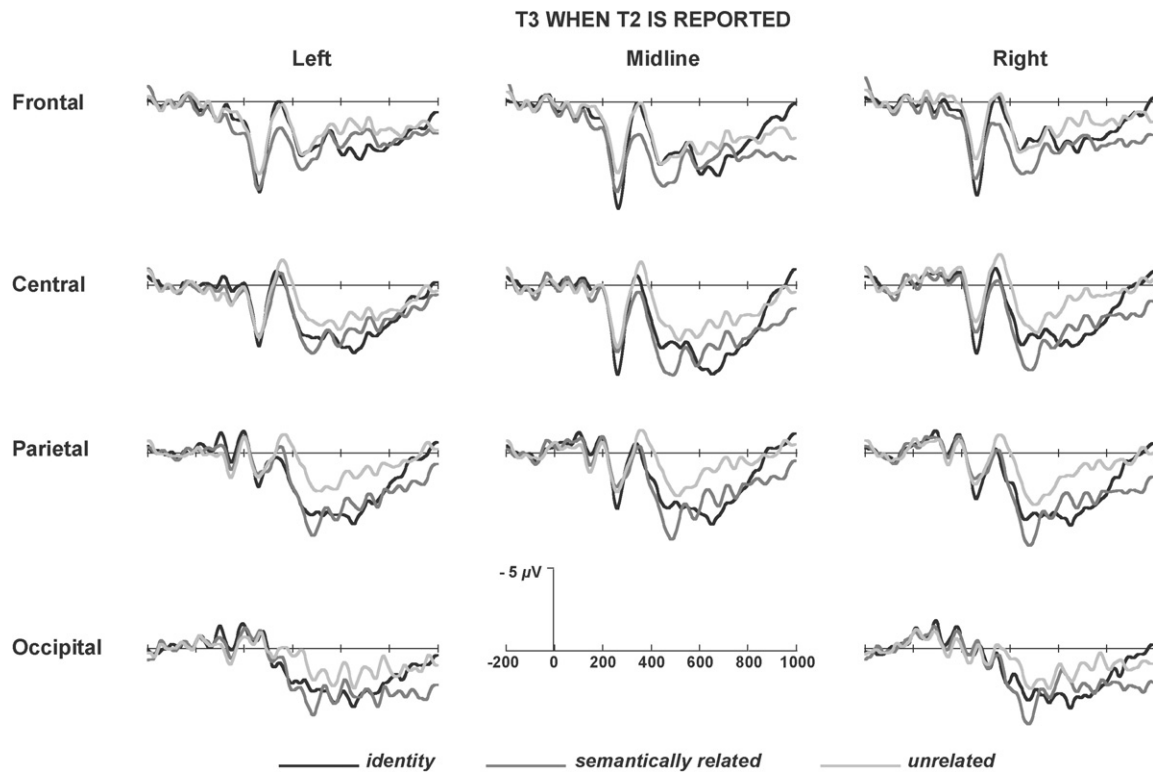
T3 WHEN T2 IS REPORTED

Fig. 4. Grand average (N = 13) ERP waveforms elicited by T3 for T2 reported. Waveforms are displayed separately for the identity (black line), semantically related (dark gray line), and unrelated (bright gray line) conditions. Electrodes shown are a representative subset, including left, midline, and right frontal electrodes (F3, Fz, F4), central (C3, Cz, C4), parietal (P3, Pz, P4), and occipital (O1, O2).

locations. There was, however, no main effect of T2 correctness, nor any reliable interaction of this factor with any of the others, indicating that the observed P2 relatedness effects were the same whether T2 was reported or 'blinked'.

Separate analyses of P2 mean amplitudes for T3 were conducted for trials when T2 was reported and when it was not. The P2 component elicited by T3 for those trials on which T2 was reported is graphically reproduced in Fig. 4.

The analysis revealed a reliable relatedness by electrode interaction, $F(32, 384) = 4.33$, $p < .001$. Specific comparisons at individual electrodes indicated reliable effects of relatedness on P2 amplitude at electrodes F4, F8, and Fz with $F(2, 24) = 5.48$, 6.02, and 4.5, respectively, all $p < .03$, and marginal effects at C4 and T4 [$F(2, 24) = 3.26$, and 3.23, respectively, both $p < .07$]. In particular, planned contrasts revealed a significant difference between the identity condition and the unrelated condition at positions F4, F8, and Fz with $F(1, 12) = 7.89$, 7.55, and 6.42, respectively, all $p < .03$, and marginal effects at C4, and T4 with $F(1, 12) = 4.45$, and 3.96, respectively, both $p < .07$, and between the semantic condition and the unrelated condition at positions F4, F8, and Fz with $F(1, 12) = 5.48$, 6.02, and 4.5, respectively, all $p < .03$, and marginal effects at C4, and T4 with $F(1, 12) = 3.08$, and 3.37, respectively, both $p < .08$. Moreover, no difference was detected between the identity and the semantic priming conditions at positions F4, F8, Fz, C4, and T4 with $F(1, 12) = .13$, $.41$, $.08$, 1.07, and 1.23, respectively, all $p > .3$. In sum, when T2 was reported P2 amplitude was modulated by

both semantic and repetition priming under conditions of rapid serial visual presentation.

The P2 component elicited by T3 on those trials on which T2 was not reported, i.e., during the attentional blink, is depicted in Fig. 5. The widespread modulation of P2 amplitude modulation by semantic and repetition condition was reliable, $F(2, 24) = 4.52$, $p < .023$. Planned contrasts indicated repetition and semantic priming from T2 in these conditions even though it was not reported [repeated versus unrelated: $F(1, 12) = 8.33$, $p < .014$, and semantically related versus unrelated: $F(1, 12) = 4.15$, $p < .05$].

Electrode specific comparisons revealed a reliable effect of relatedness on P2 amplitude at positions F4, C3, C4, T3, T4, Cz and Fz with $F(2, 24) = 5.75$, 6.91, 4.87, 4.99, 5.35, 4.70 and 5.07, respectively, all $p < .03$. Moreover, the effect of relatedness was marginally reliable at F3, $F(2, 24) = 3.11$, $p < .066$.

Despite appearances, there was no significant difference in P2 amplitude between the identity and semantic conditions, $F(1, 12) = 1.18$, $p > .3$. In sum, P2 amplitude modulation to T3 by semantic and repetition priming was observed when T2 was 'blinked' just as it was when T2 was reported.

3.4. T3-locked ERPs: 320–550 ms post-T3 (N400)

As can be seen in Fig. 4, the N400 component of the ERP to T3 for those trials on which T2 was reported was influenced by the three association conditions, with semantic and identity
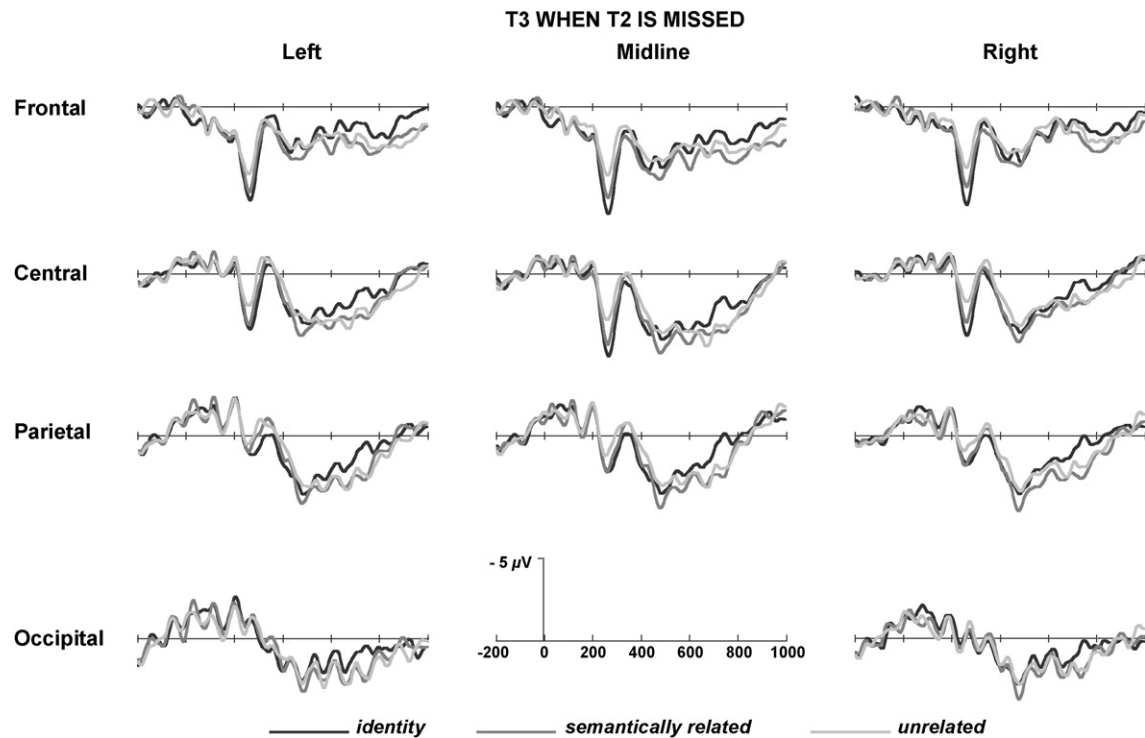
Fig. 5. Grand average ($N = 13$) ERP waveforms elicited by T3 for T2 missed. Waveforms are displayed separately for the identity (black line), semantically related (dark gray line), and unrelated (bright gray line) conditions. Electrodes shown are a representative subset, including left, midline, and right frontal electrodes (F3, Fz, F4), central (C3, Cz, C4), parietal (P3, Pz, P4), and occipital (O1, O2).

relationships producing a smaller negativity than unrelated relationship, $F(2, 24) = 6.75$, $p < .010$ [repeated versus unrelated: $F(1, 12) = 4.72$, $p < . 05$, and semantically related versus unrelated: $F(1, 12) = 10.07$, $p < .008$]. No difference was detected between the identity and semantic conditions, $F(1, 12) = 2.98$, $p > .11$.

This N400 effect was widespread but most pronounced at central-posterior sites as reflected in the relatedness by location interaction: $F(32, 384) = 4.05$, $p < .004$. Electrode specific comparisons revealed a reliable effect on N400 modulation at F4, C3, C4, P3, P4, O1, O2, T3, T4, P7, P8, Cz, and Pz with $F(2, 24) = 3.78$, 4.38, 12.22, 9.15, 10.52, 9.63, 6.13, 6.75, 18.47, 19.93, 6.40, and 8.76, respectively, all $p < .04$. The effect at Fz, $F(2, 24) = 3.30$, $p < .057$ was marginal. In the N400 time window, the difference between the identity versus semantic condition was reliable at F4, C4, T3, Fz, and Cz with $F(1, 12) = 6.96$, 5.94, 12.89, 6.16, and 5.51, respectively, all $p < .05$, and marginal ($.10 > p < .05$) at P7, P8, Pz, $F(1, 12) = 3.63$, 4.15, and 3.45, respectively.

In contrast with trials in which T2 was not reported, i.e., when T2 was 'blinked', there was no modulation of N400 amplitude with either semantic relatedness or identity $F(2, 24) = 1.12$ (see Fig. 5). In sum, the ERP in the N400 time window (unlike the P2) showed evidence of semantic and identity sensitivity only when T2 was reported but not when T2 was 'blinked'.

4. Discussion

Semantic priming and repetition priming effects on verbal report and on the ERP were examined in the context of an attentional blink (AB) paradigm. Our aim was twofold: (1) elucidating reports of ERP-behavior dissociations in the AB literature, and (2) testing Martens et al.'s hypothesis that masked repetition priming and masked semantic priming are subserved by partially, if not completely, different mechanisms. To these ends, participants were exposed to RSVP streams of letter stimuli in which three to-be-reported target words (T1, T2, T3) were embedded. T3 was either identical, semantically related, or semantically unrelated to T2. Moreover, T2 was displayed within a typical time window of an AB effect elicited by T1, and was thus often missed ('blinked'), making it possible to compare semantic priming and identity priming for reported versus 'blinked' (unreported) words. Priming was inferred from both report accuracy for identical and related T3 words versus unrelated T3 words, and ERP amplitude differences at various latencies post-T3 word onset for these same comparisons.

Whether or not T2 was reported, we observed analogous semantic and repetition priming of T3 on both accuracy and ERP measures. In other words, we did not find any dissociation between behavioral and ERP measures with regard to priming effects in this AB paradigm. Our data thus confirm and extend findings demonstrating that words falling within the AB time window are processed up to the extraction of an identity code.

Our behavioral findings, however, are partially at odds with those of Martens et al. (2002), who did not find any reliable repetition priming (Experiments 1 and 2) for 'blinked' words. One likely explanation for this discrepancy is methodological. In Martens et al.'s (Experiment 2) approximately 7 s passed between the target presentations, in contrast to only a little over

half a second (581 ms) in the present experiment. Perhaps 'blinked' words were primed in Martens et al. (2002), but priming dissipated, or was interfered with, during the 7 s interval by the processing of other words. Our behavioral data are also not in accord with those of Rolke et al. (2001), who obtained no semantic priming from 'blinked' words. Certain procedural differences—in particular, Rolke et al.'s repeated presentation of a small number of stimulus items and probing of perception with recognition of all three items embedded in a matrix of the same 24 stimulus words on every trial may help to account for this discrepancy. Both these stimulus choices could have led to learning and biases associated with different depth of semantic analyses that might obscure priming effects. The current study used many more items with no repetition and probed perception with a free report procedure; both these aspects of our design are more amenable to revealing priming, if it exists.

Additional support for the 'reality' of these priming effects comes from the parallel observation in the ERP data. Whether T2 was reported or 'blinked', it was followed by T3 priming—both identity priming and semantic priming. The pattern of priming, however, was somewhat different when T2 was reported versus 'blinked'. When T2 was reported, semantic relatedness and identity modulated amplitudes of both the P2 component and the N400 component. By contrast, when T2 was 'blinked', semantic relatedness and identity modulated P2 amplitude but had no discernible effect on the N400 component. More specifically, the amplitude of the ERP in the region of the P2 component (220–320 ms) was larger for T3 items that were repetitions of T2 or semantically related to T2, relative to items that were not related to T2 in any way, whether T2 was accurately reported or missed. This finding is generally consistent with the literature on word processing during the AB, in which it has been argued that perceptual and semantic information are extracted even from a 'blinked' stimulus (e.g., Rolke et al., 2001; Vogel et al., 1998). This same finding seems to contradict the idea that priming effects reflect the contribution of an episodic component, eventually eliminated by masking the prime as proposed by Forster and Davis (1984). If this were true we should have observed a different pattern for repeated and semantic priming conditions when T2 was reported. In this condition a memory trace of T2 has been consolidated and if we assume that this trace (a) is stronger for identity primes than for semantically related primes and (b) it contributes to priming effects, a dissociation between repeated and semantic priming should have been observed.

One might argue the 'blinked' T2 was merely forgotten by the time of report, even though it had been fully processed upon presentation, because verbal report was delayed by a few seconds laden with interfering items. The differential P300 for reported versus 'blinked' T2 items does not, however, support this account: the P300 to missed T2 items was significantly attenuated relative to that for reported T2 items. Under the hypothesis that the P300 reflects some aspect of working memory updating/consolidation (Donchin, 1981; Donchin and Coles, 1988), this finding indicates that the AB seems to operate before or at the same time as a representation of the stimulus is being formed in working memory, and that its consolidation is not completed when T2 is 'blinked' (see Vogel et al., 1998).

These findings support the view that AB occurs at some post-perceptual stage. That said, it is important to note that our findings are not contingent upon any particular account of the exact locus of the limited capacity process that underlies AB (for more details, see e.g., Chun and Potter, 1995; Jolicœur, 1999; Shapiro et al., 1994), as in our design AB was just a vehicle to yield masked repetition and semantic priming effects.

Whereas we expected to see semantic priming effects in the ERP, we had not expected to see these effects quite so early—i.e., in the P2 window (220–320 ms). The P2 component, however, has been shown to be sensitive to word identification (e.g., Barnea and Breznitz, 1998; Kramer and Donchin, 1987) and to word repetition (e.g., Misra and Holcomb, 2003; Rugg, 1987). More specifically, Barnea and Breznitz (1998) and Kramer and Donchin (1987) found an early P2 component in a phonological and orthographic task in Hebrew and in English, respectively. They found the largest P2s when both the orthographic and phonological features of word pairs differed, intermediate when either orthography or phonology differed, and smallest when orthography and phonology were congruent. They suggested that the extraction of the orthographic and phonological features of words may occur at the stimulus classification stage relatively early in the information-processing stream. Moreover, Misra and Holcomb (2003) observed, in a semantic categorization task, an enhanced P2 for targets that were immediate repetitions of their primes, whether or not the primes were masked. Rugg (1987) also found a P2 modulation, primarily over frontal sites, for repeated items in an oddball word/non-word count task, suggesting that the information about the immediate recurrence of an item may be available by no later than 200 ms post-stimulus. We also cannot rule out the possibility that the early P2 effect reflects an earlier onset of N400 attenuation with relatedness in this particular experimental condition. Very fast lexical access would be in line with a recent work by Dell'Acqua et al. (2007b), who found that the N2pc component elicited by a lateralized target word identified on the basis of color was systematically affected by the associative relationship between the target word and a distractor word displayed in the opposite hemifield. N2pc amplitude was attenuated when target and distractor words were related compared when they were not, with this relatedness difference emerging as early as 170–180 ms after the presentation of the word pair.

In those cases where T2 was reported, the P2 modulation was accompanied by an N400 attenuation on T3 for identical and semantically related items; perhaps surprisingly, there was no such N400 modulation for T3 when T2 was 'blinked'. On the view that N400 activity indexes semantic integration and not just semantic access (Holcomb, 1993), it is possible that when 'blinked', T2 was not active for a sufficient amount of time to establish a context for semantic integration. While this also may have been the case in the Rolke et al.'s study for any given trial, they used a small number of contexts that were often repeated, thereby increasing the resting level of T2 so as to possibly

support priming, even when it was 'blinked'. The results of this and other ERP masked priming studies are not inconsistent with some version of semantic integration hypothesis, according to which the N400 (at least under masked conditions) reflects a lexical integration process that requires attention to the semantic properties of the eliciting stimulus.

Our findings also speak to the issue of the identity of the mechanisms of masked semantic priming and masked repetition priming. Both the behavioral accuracy data and ERP (P200 and N400) data revealed no differences in the amount of semantic and repetition. By these measures, then, semantic and repetition priming at least under masking appear to engage similar mechanisms (here refer back to citations about this in introduction). These results are in accord with fMRI data indicating that these two types of priming activate the same regions of the brain (Copland et al., 2003; Kotz et al., 2002; Mummery et al., 1999). Our findings, however, are not consistent with research on unmasked and masked repetition priming and semantic priming showing that they are different. For instance, repetition priming has been found to be longer lasting than semantic priming (Bentin and Feldman, 1990; Henson, 2003; Schacter and Buckner, 1998). Moreover, ERP repetition priming effects are often larger in magnitude and duration, and sometimes present with different scalp topographies than semantic priming effects (Rugg, 1987). In one report, prime visibility plays a bigger role in mediating masked semantic priming than in masked repetition priming (Holcomb et al., 2005). Direct comparisons between investigations of these two priming effects, however, are difficult given stimulus, task, and methodological differences (e.g., SOA, proportion of relation, masking). Moreover, it is possible that participants adopt different processing strategies when items are either semantically primed or identical but not both. The few investigations that have compared the two directly have produced mixed results. Rugg (1985), in a lexical decision with unmasked targets, found similar effects on the N400 for both types of priming. In contrast, Rugg (1987), in a silent count of occasional non-words with unmasked targets, described N400 differences for the two types of priming. Raposo et al. (2006) likewise reported differences – specifically in pattern of fMRI activations for repetition and semantic priming – which they took as evidence for distinct cognitive processes and neural substrates.

To conclude, we find that at least under some conditions there is a remarkable similarity between semantic and repetition accuracy and ERP priming effects—temporally, qualitatively, and in the case of ERP topographies as well. As this contrasts with Martens et al.'s conclusion that these types of priming effects rely on wholly different mechanisms, it will be important to determine the exact conditions under which the two behave similarly versus differently.

References

Barnea, A., Breznitz, Z., 1998. Phonological and orthographic processing of Hebrew words: electrophysiological aspects. Journal of Genetic Psychology 159, 492–504.

Bentin, S., Feldman, L.B., 1990. The contribution of morphological and semantic relatedness to repetition priming at short and long lags: evidence from Hebrew. Quarterly Journal of Experimental Psychology 42, 693–711.

Bodner, G.E., Masson, M.E.J., 2003. Beyond spreading activation: an influence of relatedness proportion on masked semantic priming. Psychonomic Bulletin & Review 10, 645–652.

Broadbent, D.E., Broadbent, M.H.P., 1987. From detection to identification: response to multiple targets in rapid serial visual presentation. Perception & Psychophysics 42, 105–113.

Carr, T.H., Dagenbach, D., 1990. Semantic priming and repetition priming from masked words: evidence for a center-surround attentional mechanism in perceptual recognition. Journal of Experimental Psychology: Learning, Memory, and Cognition 16, 341–350.

Chun, M.M., Potter, M.C., 1995. A two-stage model for multiple target detection in rapid serial visual presentation. Journal of Experimental Psychology: Human Perception and Performance 21, 109–127.

Collins, A.M., Loftus, E.F., 1975. A spreading-activation theory of semantic memory. Psychological Review 82, 407–428.

Copland, D.A., de Zubicaray, G.I., McMahon, K., Wilson, S.J., Eastburn, M., Chenery, H.J., 2003. Brain activity during automatic semantic priming revealed by event-related functional magnetic resonance imaging. Neuro-Image 20, 302–310.

Dell'Acqua, R., Jolicœur, P., Pesciarelli, F., Job, R., Palomba, D., 2003. Electrophysiological evidence of visual encoding deficits in a crossmodal attentional blink paradigm. Psychophysiology 40, 629–639.

Dell'Acqua, R., Jolicœur, P., Pascali, A., Pluchino, P., 2007a. Short-term consolidation of individual identities leads to lag-1 sparing. Journal of Experimental Psychology: Human Perception and Performance 33, 593–609.

Dell'Acqua, R., Pesciarelli, F., Jolicœur, P., Eimer, M., Peressotti, F., 2007b. The interdependence of spatial attention and lexical access as revealed by early asymmetries in occipito-parietal ERP activity. Psychophysiology 44, 436–443.

Di Lollo, V., Enns, J.T., Rensink, R.A., 2000. Competition for consciousness among visual events: the psychophysics of reentrant visual processes. Journal of Experimental Psychology: General 129, 481–507.

Donchin, E., 1981. Surprise!... Surprise? Psychophysiology 18, 493–513.

Donchin, E., Coles, M.G.H., 1988. Is the P300 component a manifestation of context updating? Behavioral and Brain Sciences 11, 357–374.

Duncan, J., Martens, S., Ward, R., 1997. Restricted attentional capacity within but not between sensory modalities. Nature 387, 808–810.

Forster, K.I., Davis, C., 1984. Repetition priming and frequency attenuation in lexical access. Journal of Experimental Psychology: Learning, Memory, and Cognition 10, 680–698.

Gratton, G., Coles, M.G., Donchin, E., 1983. A new method for off-line removal of ocular artifact. Electroencephalography and Clinical Neurophysiology 55, 468–484.

Henson, R.N.A., 2003. Neuroimaging studies of priming. Progress in Neuro-biology 70, 53–81.

Holcomb, P.J., 1993. Semantic priming and stimulus degradation: implications for the role of N400 in language processing. Psychophysiology 30, 47–61.

Holcomb, P.J., Reder, L., Misra, M., Grainger, J., 2005. Masked priming: an event-related brain potential study of repetition and semantic effects. Cognitive Brain Research 24, 155–172.

Jolicœur, P., 1999. Restricted attentional capacity between sensory modalities. Psychonomic Bulletin & Review 6, 87–92.

Kotz, S.A., Cappa, S.F., von Cramon, D.Y., Friederici, A.D., 2002. Modulation of the lexical-semantic network by auditory semantic priming: an event-related functional MRI study. NeuroImage 17, 1761–1772.

Kramer, A.F., Donchin, E., 1987. Brain potentials as indices of orthographic and phonological interaction during word matching. Journal of Experimental Psychology: Learning, Memory, and Cognition 13, 76–86.

Kutas, M., Hillyard, S.A., 1980. Reading senseless sentences: brain potentials reflect semantic incongruity. Science 207, 203–205.

Lamme, V.A., 2003. Why visual attention and awareness are different. Trends in Cognitive Sciences 7, 12–18.

Logan, G.D., 1988. Toward an episode theory of automatization. Psychological Review 95, 492–527.

Luck, S., Vogel, E.K., Shapiro, K.L., 1996. Word meanings can be accessed but not reported during the attentional blink. Nature 383, 616–618.

Maki, W.S., Frigen, K., Paulson, K., 1997. Associative priming by targets and distractors during rapid serial visual presentation: does word meanings survive the attentional blink? Journal of Experimental Psychology: Human Perception and Performance 23, 1014–1034.

Marcel, A.J., 1983. Conscious and unconscious perception: experiments on visual masking and word recognition. Cognitive Psychology 15, 197–237.

Martens, S., Wolters, G., van Raamsdonk, M., 2002. Blinks of the mind: memory effects of attentional processes. Journal of Experimental Psychology: Human Perception and Performance 28, 1275–1287.

Masson, M.E.J., Bodner, G.E., 2003. A retrospective view of masked priming: toward a unified account of masked and long-term repetition priming. In: Kinoshita, S., Lupker, S.J. (Eds.), Masked Priming: The State of the Art. Psychology Press, New York, pp. 57–94.

Misra, M., Holcomb, P.J., 2003. Event-related potential indices of masked repetition priming. Psychophysiology 40, 115–130.

Mummery, C.J., Shallice, T., Price, C.J., 1999. Dual-process model in semantic priming: a functional imaging perspective. NeuroImage 9, 516–525.

Neely, J.H., 1977. Semantic priming and retrieval from lexical memory: roles of inhibitionless spreading activation and limited capacity attention. Journal of Experimental Psychology: General 106, 226–254.

Neely, J.H., 1991. Semantic priming effects in visual word recognition: a selective review of current findings and theories. In: Besner, D., Humphreys, G.W. (Eds.), Basic Processes in Reading. Erlbaum, Hillsdale, NJ, pp. 264–336.

Pivik, R.T., Broughton, R.J., Coppola, R., Davidson, R.J., Fox, N., Nuwer, M.R., 1993. Guidelines for the recording and quantitative analysis of electroencephalographic activity in research contexts. Psychophysiology 30, 547–558.

Potter, M.C., Chun, M.M., Banks, B.S., Muckenhoupt, M., 1998. Two attentional deficits in serial target search: the visual attentional blink and an amodal task-switch deficit. Journal of Experimental Psychology: Learning, Memory, and Cognition 24, 979–992.

Raposo, A., Moss, H.E., Stamatakis, E.A., Tyler, L.K., 2006. Repetition suppression and semantic enhancement: an investigation of the neural correlates of priming. Neuropsychologia 44, 2284–2295.

Raymond, J.E., Shapiro, K.L., Arnell, K.M., 1992. Temporary suppression of visual processing in an RSVP task: an attentional blink? Journal of Experimental Psychology: Human Perception and Performance 18, 849–860.

Rolke, B., Heil, M., Streb, J., Hennighausen, E., 2001. Missed prime words within the attentional blink evoke an N400 semantic priming effect. Psychophysiology 38, 165–174.

Rugg, M.D., 1985. The effects of semantic priming and word repetition on event-related potentials. Psychophysiology 22, 642–647.

Rugg, M.D., 1987. Dissociation of semantic priming, word and non-word repetition effects by event-related potentials. Quarterly Journal of Experimental Psychology 39, 123–147.

Schacter, D.L., Buckner, R.L., 1998. Priming and the brain. Neuron 20, 185–195.

Shapiro, K.L., Raymond, J.E., 1994. Temporal allocation of visual attention: inhibition or interference? In: Dagenbach, D., Carr, T.H. (Eds.), Inhibitory Processes in Attention, Memory, and Language. Academic Press, San Diego, CA, pp. 151–188.

Shapiro, K.L., Raymond, J.E., Arnell, K.M., 1994. Attention to visual pattern information produces the attentional blink in rapid serial visual presentation. Journal of Experimental Psychology: Human Perception and Performance 20, 357–371.

Shapiro, K., Driver, J., Ward, R., Sorensen, R.E., 1997. Priming from the attentional blink: a failure to extract visual tokens but not visual types. Psychological Science 8, 95–100.

Tenpenny, P.L., 1995. Abstractionist versus episodic theories of repetition priming and word identification. Psychonomic Bulletin & Review 2, 339–363.

Tulving, E., 1983. Elements of Episodic Memory. Clarendom Press, Oxford.

VELI (Vocabolario elettronico della lingua italiana), 1989. IMB, Italia (Electronic vocabulary of Italian language).

Vogel, E.K., Luck, S.J., Shapiro, K.L., 1998. Electrophysiological evidence for a post-perceptual locus of suppression during the attentional blink. Journal of Experimental Psychology: Human Perception and Performance 24, 1656–1674.